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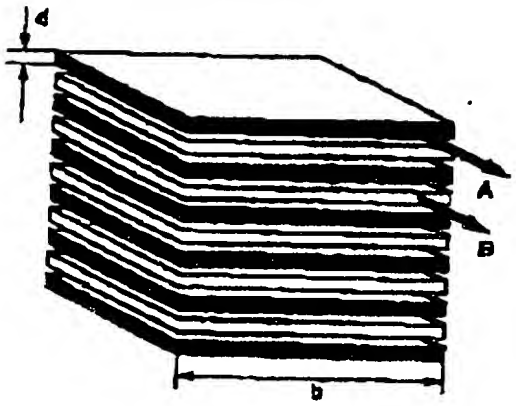
54 Process and Device for the Performance of Chemical Reactions by means of a Microstructure Lamellae Mixer[1]

[57] In this reaction process, a minimum of two educts A, B are each subdivided by an associated system of slit-shaped microchannels 1a, 1b, into spacially separated fluid lamellae, which then emerge into a common mixing and reaction chamber 4. The fluid lamellae have thereby a density of < 1000 µm, preferably < 100 µm, with a width/thickness ratio of at least 10. Essential thereby is that one lets the educts A, B emerge into the mixing/reaction chamber 4 as thin fluid lamellae 6a, 6b, whereby each fluid lamella 6a of an educt A is lead into the mixing/reaction chamber 4 in the direct vicinity of a fluid lamella 6b of another educt B. The neighboring fluid lamellae 6a, 6b then mix through diffusion and/or turbulence. Through that, the mixing process accelerated considerably in comparison to conventional reactions. In this way, with rapid chemical reactions one prevents to a large extent the formation of undesired by-products or secondary products.



Research Center
[1] sic, duplicated in the original
[2] literal translation

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Description

To perform a chemical reaction in a continuous mode of operation, the partners in a reaction must be fed continuously into a chemical reactor and brought into intimate contact, i.e., mixed well by means of a mixing element (mixer). A simple reactor is, e.g., a container with a stirrer as the mixing element. A plurality of reactions, so-called primary and secondary reactions, usually take place in the reactor at the contact of the reactants. The goal of the process is thereby to conduct the reaction and with it also the mixing such that a yield as high as possible is achieved selectively of the desired products.

The mixing quality and the influence of the mixing element on the yield of desired products is thereby to a great extent dependent on the ratio between the reaction rate determined by the reaction kinetics and the rate of mixing. If in the case of the chemical reaction one deals with slow reactions, then the chemical reaction is usually considerably slower than the mixing. The overall reaction rate and the yield for desired products is[1] then determined by the slowest step, namely the kinetics of the chemical reactions that are running, and in addition by the general mixing behavior (retention time distribution, macroscopic mixing) of the chemical reactor used. If the chemical reaction rate and the rate of mixing lie within the same order of magnitude, then one gets more complex interactions between the kinetics of the reactions and the local mixing behavior determined by turbulence in the reactor used and next to the mixing element (micromixing). If it happens that the chemical reaction rates are considerably faster than the rate of mixing, then the overall rates of the reactions taking place and the yields are basically determined by the mixing, i.e., through the local, time-dependent velocity and concentration field of the reactants, i.e., the turbulence configuration in the reactor and in the proximity of the mixing element [1].

According to the state of the art, a series of mixing elements are used for performing rapid reactions in the continuous mode of operation. Here one may differentiate between dynamic mixers like, e.g., stirrers, turbine [mixers] or rotor-stator systems, static mixers

[1] sic. *are* was probably intended

like, e.g., Kenics mixers, shish-kebab mixers* or SMV mixers and jet blenders like, e.g., jet mixers or t-mixers [2-4].

jet mixers are used with preference for the rapid mixing of the starting materials for rapid reactions with undesired subsequent or secondary reactions.

With jet or jet mixers, one of the two starting components is atomized with a high flow velocity into the other component (see Fig. 1). The kinetic energy of the jet-fed stream (B) is thereby essentially dissipated behind the nozzle, i.e., transformed into vortices through the turbulent break-up of the stream and into heat through the break-up of the vortices into smaller and smaller vortices. Comprised in the vortices are each of the starting components which in the plumes are present next to one another (macromixing). At the beginning of the turbulent break-up of the vortices, a slight mixing through diffusion indeed takes place at the edges of these initially larger structures. But the complete mixing is only achieved when the break-up of the vortices has proceeded so far that with reaching vortex dimensions on the order of the concentration microdimension (Batchelor length) [5, 6], the diffusion is rapid enough for a complete mixing of the starting components in the vortices. In addition to the material data and the geometry of the equipment, the time necessary for the complete mixing is essentially dependent on the specific energy dissipation rate*.

The mixing processes with the mixers that are often used according to the state of art are in principal similar (with dynamic mixers and static mixers, the vortices are furthermore broken up mechanically, however, at usually considerably lower specific energy dissipation rates). This means that with the mixers utilized according to the state of the art, the time that passes until complete mixing through diffusion [is achieved] is always the vortex break-up [time]. For very fast reactions this means that one must either adjust to very high rates of energy dissipation in order to avoid undesired secondary or subsequent reactions, or with reactions with even higher reaction rates the corresponding reactions are performed not to the optimum, i.e., only with the formation of secondary or by-products.

Starting out from this state of the art, the object of the invention is in making available a process and a device in which the mixing takes place rapidly and the formation of by-products and secondary products is suppressed or reduced. Thereby one

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* literal translation

must achieve that the educts are homogeneously mixed with one another such that within the shortest time there appear no longer any local nor temporal hyperconcentration of the educts. With fluids chemically reacting with one another one must achieve a complete reaction of the fluids. The heat of reaction shall also be able to be supplied or removed effectively and as quickly as possible as needed.

The means for attaining this object according to the invention are in a process in which at least two educts A, B are each subdivided by an associated system of slit-shaped micro-channels (micro-slit channels) in a microstructure mixer, into spacially separated fluid lamellae, which then emerge at flow rates equal for each of the educts into a mixing/reaction chamber, whereby each fluid lamella of an educt A is lead into the mixing and reaction chamber in the direct vicinity to a fluid lamella of another educt B and the neighboring fluid lamellae mix with one another through diffusion and/or turbulence. Under a micro-slit channel one thereby understands a rectangular microchannel with a depth d, the width b of which >=[7] 10d (b/d >= 10), preferably b >= 20d (b/d >= 20).

Laminar flow conditions are preferably maintained for the educts A, B in the microchannels. But there is nothing that stands in the way of possibly working with turbulent flows in the micro-slit channels.

An embodiment in which the fluid lamellae of the educts emerge into the mixing/reaction chamber in layers lying alternating one atop another or next to one another is particularly reliable.

The geometry of the microstructure lamellae mixer is advantageously laid out such that the thickness of the fluid lamellae d at the inlet into the mixing/reaction chamber can be adjusted to a value between 10 µm and 1000 µm, preferably between 10 µm and 100 µm. One preferably adjusts to a thickness d which lies in the microdimension of the concentration, such that after the emergence from the microstructure mixer, a micromixing of the components may quickly take place through diffusion, without a further vortex break-up being necessary. The width b of the fluid lamellae or of the microslit channels through which the lamellae emerge out of the microstructure lamellae mixer should thereby be as large as possible in order to keep the loss of pressure in the

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[6] literal translation

[7] ≥ probably intended

mixer as low as possible by decreasing the wall surface per volume of educt. The width b may thereby be varied from values in the range of the order of magnitude of 0.5 mm up to large values in the range of several centimeters, and is limited only through the mechanical stability of the structural element. Crucial thereby for the mixing rate and thus the quality of mixing is a thickness d of the fluid lamellae as small as possible, but not the width b.

A development of the process according to the invention consists in that in the vicinity of a fluid lamella of an educt, a fluid lamella of a thermostated inert fluid is further fed into the mixing/reaction chamber, e.g., for heating or cooling purposes.

The process according to the invention is thus based on [the fact] that the educt flows A, B are at first convectively subdivided by means of the microstructure lamellae mixer into thin lamellae with a thickness d which then, after emerging into the mixing/reaction chamber, mix with one another through diffusion and/or turbulence.

The object of the microstructure lamellae mixer is thereby to subdivide the educt flows convectively and to create fine fluid lamellae with a characteristic thickness d, without the starting components coming into contact with one another within the mixing device. Through the equal geometric dimensioning (equal cross-section and equal length) for the microslit channels associated with each educt it is ensured that the fluid lamellae emerging from all channels associated with one educt emerge at the same flow rate. With two educts A, B, the flow rates in the microslit channels are thus the same for one educt. But the flow rates of the two educts (in relation to one another) may absolutely be different [from one another].

The device according to the invention makes it possible to essentially eliminate the time for the turbulent break-up during the mixing and by that considerably accelerate the process of mixing. One achieves the mixing behavior of a nearly ideal tube reactor by dividing the educt streams into thin fluid lamellae whit the thickness d within the microstructure, without the educt streams coming into contact with one another, and through the homogeneous distribution of the educts at the output of the microstructure. With rapid reactions, undesired secondary or by-products appear to a considerably lesser extent than with mixers according to the state of the art. A main application are thus rapid reactions which have characteristic reaction times <10 s and in particular of <1 s. Under "reaction time" one usually understands the [reaction] half-life, i.e., the period of time

after the start of the reaction after which the educt concentration has dropped to half its value.

A stationary microstructure lamellae mixer with at least one mixing chamber and a preceding structural guiding part for the supply of mixing and reaction fluids (educts) proved worthwhile as apparatus. The structural guiding part is thereby composed of a plurality of plate-like elements layered on top of one another, which are passed through by microchannels running diagonally with respect to the longitudinal axis of the micromixer, whereby the channels of neighboring elements cross-over contact-free and emerge into the mixing chamber. According to the invention, this device is characterized by the following characteristics:

a) The plate-like elements consist of thin foils into each of which are incorporated individual or a system of closely neighboring, slit-shaped microslit channels that run with alternating opposite inclinations to the longitudinal axis of the micromixer, such that when layering the foils on top of one another, a of closed channels row forms each time for the guiding of the fluids to be mixed (educts A, B).

b) The microslit channels have a depth of $d < 1000$ µm, preferably < 100 µm, with wall thicknesses of the intermediate bridges and channel bases of < 1000 µm, preferably < 100 µm and a width which is at least 10 times, preferably 20 times the depth d.

c) Towards the fluid input side of the micromixer, the microslit channels of neighboring foils diverge such that the fluids to be mixed (educts A, B) may be injected separately.

In order to improve the mechanical stability, pins or bridges may be applied vertically off the channel bases, which are rigidly connected to the channel bases and support them against one another.

Alternately, an intermediate foil is intercalated between each two foils with the inclined microslit channels diverging towards the fluid input side, which [intermediate foil] has microslit channels running perpendicularly to the longitudinal axis of the micromixer and serves in guiding through a cooling or heating agent.

According to a further alternative, a micro-heat-transfer [system] is connected to the mixing chamber. But the mixing chamber may itself be designed as micro-heat-transfer [system] which is connected directly to the structural guiding part.

With the device according to the invention, the fluids to be mixed are subdivided in rows and staggered into thin, neighboring fluid lamellae which, when brought together at the entrance into the mixing chamber, fill out a common, correspondingly tightly limited volume and by that can mix through and through in the fastest and shortest way. The formation of extremely thin fluid lamellae allows for a few hundred to thousand lamellae lying above or next to one another within a height of 1 cm, and these fluid lamellae are alternately supplied with educt A and educt B.

The device according to the invention makes possible the mixing of two or more fluids. If fluids (educts) chemically reacting with one another are mixed, then the heat of reaction arising (exothermic reactions) or needed (endothermic reactions) may be dissipated or supplied via the connected micro-heat-transfer [system].

The following advantages may be achieved when utilizing the device according to the invention:

- Improvement of the yield, selectivity and product quality with known reactions
- Preparation of products with new profile of properties (e.g., higher [degrees of] purity)
- Miniaturizing of reactors and mixers, possibly in combination with heat exchangers
- Improvement of the safety standard for exothermic reactions by decreasing the hold-up [time] and possibly by reducing the dimensions of the microslit channels to below the put-out distance* (improved security against back-firing!)
- The contact surface between [the] fluid and the channel wall is minimized through the slit-shaped design of the microchannels (channel width b » channel depth d). In the case of a microstructure lamellae mixer, in particular for a channel depth $d < 100\ \mu m$, this leads to clearly lower pressure losses through friction than in a microstructure mixer for which the microslit channels lie in the order of magnitude of the depth d (approximately square cross-section)

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* literal translation

- By generating fluid lamellae in the device according to the invention in place of a larger number of fluid filaments[9] separated by walls, the back-mixing which may take place in the space between the individual fluid filaments[10] right when entering the mixing space because of local vortices at the orifices is reduced and with it the formation of by-products.
- Furthermore, the danger of clogging is reduced considerably with respect to the micromixer with many, nearly square microchannels.

In the following, the invention is explained more closely by means of examples of embodiment and drawings. [The figures] show

Fig. 1 the mixing of two educts A, B in a flat jet mixer or tube reactor (state of the art)

Fig. 2 the schematic representation of fluid lamellae lying above one another

Fig. 3 the basic construction of a preferred embodiment of the microstructure lamellae mixer for two educts A, B with symmetric flow passages,

Fig. 4 the mixing of the fluid lamellae associated with the educts A, B entering the mixing and reaction chamber from the microstructure lamellae mixer,

Fig. 5a and **5b** an embodiment in which the spacial arrangement of the fluid lamellae associated to the educts A, B when entering the mixing/reaction chamber is characterized by alternating layers lying above or next to one another.

Fig. 6 a flow schematic of an apparatus for the investigation of chemical reactions which run by using the device according to the invention

Fig. 7 Results for the azo coupling reaction of α-naphthol with sulfobenzene diazonium salt when using a microstructure lamellae mixer, in comparison with a microstructure mixer with [a] nearly square channel cross-section and a conventional and flat jet reactor

Fig. 8a a plurality of stacking foils as structural elements for the microstructure lamellae mixer, with one microslit channel each per foil

Fig. 8b and **8c** two views of a structural guiding element [built] from foils according to **Fig. 8a**

Fig. 8d schematically [shows] the flow pattern in a microstructure lamellae mixer

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[9] literal translation
[10] literal translation

Fig. 9a and **9b** schematically [shows] a microstructure lamellae mixer with [a] structural guiding element that may be cooled or heated.

Fig. 10a a section through a microstructure lamellae mixer, attached to the mixing chamber of which there is a heat-transfer [system]

Fig. 10b a microstructure lamellae mixer with a mixing chamber designed as heat-transfer [system].

According to **Fig. 1**, two educts A, B reacting with one another are fed into a flat jet mixer or flat jet nozzle reactor according to the state of the art. Here, the educt B is jet-blasted with a speed different [from A] into the educt stream A supplied through the concentric annular space between the jet nozzle and the wall of the reactor. It comes to an intensive mixing (formation of vortices) and the immediate start of the chemical reaction between the educts or reactants A, B.

Fig. 2 shows the principle at the basis of the invention of fluid lamellae layered alternating on top of one another. A lamellae of the fluid B follows each time a lamellae consisting of the fluid A. The thickness d of the lamellae is thereby small with respect to their width b. The fluids A, B may consist of a gas or a fluid and in the following are designated as [the] educts A, B.

An embodiment of a microstructure lamellae mixer or reactor corresponding to the device according to the invention is represented schematically in **Fig. 3**. The basic construction of this mixer/reactor is based on [the fact] that various layers of the plates, with microslit channels running diagonally, are stacked vertically on top of one another in a sandwich-type construction.

Each of the plates with microslit channels 1a is followed by a plate with the microslit channels 1b, i.e., two plates in a stack arranged directly on top of one another are each provided with a system of microslit channels 1a, 1b, whereby the microslit channel systems of subsequent plates form with one another an angle α and are arranged symmetrically to the horizontal axis in **Fig. 3**, i.e., as a mirror image of one another. The plates have, e.g., a thickness of 100 µm. The slit channels have, e.g., a depth d of 70 µm and a width $b > 700$ µm.

When seen from the center of the image[1], the systems of microslit channels 1a in **Fig. 3** running diagonally upwards end on the left side in a distributor chamber 3a, to which a reactant or an educt A may be supplied. Analogously, the systems of microslit channels 1b running diagonally downwards end on the left side in a distributor chamber 3b, to which an educt B (reactant) may be supplied. Without intersecting, both systems of microslit channels end on the right side in a common mixing/reaction chamber 4. The symmetrically mirroring arrangement of the microslit channels 1a, 1b is not absolutely necessary. The microslit channels 1b may also have, e.g., another inclination with respect to the horizontal axis than the microslit channels 1a.

Important, however, is that all of the microslit channels of one system are equal from a flow-technological point of view, i.e., that the microslit channels 1a have all the same flow resistance. The same condition is valid for the flow resistance of the microslit channels 1b, but where the flow resistances of the two systems of microchannels 1a, 1b may be different (with respect to one another). The same flow resistance may be achieved in that the length and the cross-section for all microslit channels 1a are the same.

The educt, e.g., a reactant in the form of a gas, supplied to a distributor chamber 3a, 3b is distributed over the microslit channels 1a, 1b, respectively. The combination of both reactants occurs when entering into the mixing/reaction chamber and described more closely in the following by means of the **Fig. 4** and **5**. In **Fig. 4**, the orifice cross-section of the microstructure lamellae mixer is represented in perspective.

In the most upper layer or plate, the microslit channels 1a, associated, e.g., to the educt A, and in the following layer or plate lying underneath, the microslit channels 1 of the educt B emerge into the mixing/reaction chamber. Hereto follows again a layer or plate with the microslit channels belonging to the educt A, etc. Also represented schematically in **Fig. 4** is how the fluid streams guided in the microslit channels enter the mixing/reaction chamber as fluid lamellae 6a, 6b and mix with one another with an increasing distance from the entrance. The mixing thereby takes place through diffusion and/or turbulence, whereas laminar flow conditions usually predominate in the microslit channels. The reaction of the educts A, B also starts simultaneously with the mixing. The product of the reaction is removed at the end of the mixing/reaction chamber (see **Fig. 3**).

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[1] this description would be dependent on which way one holds the page - in this case "landscape" is intended.

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In **Fig. 5** it is again shown in what spacial sequence the educts A, B reach the mixing/reaction chamber at the cross-section op the orifice. Each layer with fluid lamellae of the educt A thus borders against a layer of the fluid lamellae of the educt B The arrangement may naturally also be rotated by 90°, such that the layers lie next to one another.

The microstructure lamellae mixer according to **Fig. 3** may also be modified such that three or more educts are each separated into separate systems of microslit channels, which are then brought together in the mixing/reaction chamber. An interesting variation from a process-technological point of view consists in that the third educt consists of a thermostated inert fluid. The fluid lamellae are then guided into the microstructure lamellae mixer such that for heating or cooling purposes, a fluid lamella of the thermostated inert fluid is fed into the mixing/reaction chamber in the vicinity to a fluid lamella of an educt.

A practical embodiment of the microstructure lamellae mixer which has proven itself in particular is described in the following by means of the **Fig. 8a** through **10b**.

The foils 1 and 2 according to **Fig. 8a** have a thickness of 100 µm. The foil type 1 is run through by one [individual] or a system of preferably parallel, closely adjacent microslit channels running at an angle to the longitudinal axis of mixing 3, which starting from the left back, form an acute angle $+\alpha$ with this axis 3 and emerge in the central region of the longitudinal front side of the foil. The foil type 2 is run through in the same way by microslit channel 1b; but in this case, the angle between the longitudinal axis of the groove and the longitudinal axis of the mixer is $-\alpha$; i.e., the microslit channel runs from the right back to the central region of the longitudinal front side of the foil. However, the value of the angle must not be the same. The microslit channels 1a, 1b may be created, e.g., with diamond profiling [tools] and preferably have a width $b > 700$ µm and a depth d of 70 µm. The thickness of the channel bases 5a, 5b is 30 µm.

In the case of broad microslit channels it may be useful to support the foils or channel bases 5a, 5b against one another through perpendicularly arranged, continuous pins 15 or bridges with small transverse dimensions, which are soldered to the channel bases. In this way, the microslit channels 1a, 1b may be designed as broad as desired without compromising the mechanical stability.

Fig. 8b and **8c** show how, in order to produce a structural guiding part 6, the foil types 1 and 2 are placed in alternation on top of one another, are provided with a top and a bottom cover plate 7a, 7b, and are bonded together, e.g., by means of diffusion welding into a homogeneous, vacuum-tight and pressure-resistant microstructure element.

These microslit channels 1a, 1b form a common block having, e.g., a square cross-section, with a thickness of a few tens up to a few hundreds of orifices per cm^2 which border the common mixing chamber 4. **Fig. 8c** shows the structural guiding part 6 as seen from the feed side for the fluids A and B. As may be gathered from this and from the top view according to **Fig. 8d**, the channels 1a, 1b running at an angle to the longitudinal axis 3 diverge starting at the mixing chamber 4, alternating towards the entry side of the fluid such that the fluids A and B can be supplied separately to the structural guiding part 6, from one entry chamber or distributor chamber 3a and 3b each. After emerging from the structural guiding part 6, the fine fluid lamellae 6a, 6b of the fluids A and B are intimately mixed with one another and form in the mixer chamber 4 one combined stream C (see also Fig. 4).

The **Fig. 9a** and **9b** show a variation in which intercalated between two foil types 1 and 2, and between the foils and the cover plates 7a, 7b, there are intermediate foils 8 which have microslit channels 9 running perpendicularly to the longitudinal axis 3, for passing through a cooling or heating agent. Through that one may influence the time of mixing and the reaction rate of the fluids A and B.

In **Fig. 10a**, structural guiding part 6 corresponding to the **Fig. 8a** and **8b** is represented as a section, with mixing chamber 4 connected. Furthermore connected to this mixing chamber there is a heat-transfer [system] 10 which similarly to the variation according to **Fig. 9a** and **9b**, is traversed by channels 11a running perpendicularly to the flow direction C, for supplying or removing the reaction heat to or from the channels 11b.

In **Fig. 10b**, the heat-transfer [system] 12 is connected directly to the structural guiding part 13. The separation through distancing foils 14 is thereby made such that each two channels 13a, 13b for the fluids A, B feed into one common partial mixing space 12a of the heat-transfer [system], whereby the partial mixing space 12a border foils 12b which have channels 12c running perpendicularly to the direction of flow C. These channels 12c carry a cooling or heating agent by means of which heat relating to the mixing and reactions zones may be removed or supplied.

Example

The azo coupling reaction of α-naphthol with sulfobenzene diazonium salt is used in the literature for evaluating the mixing behavior of various mixing devices [2, 8, 9]. This reaction corresponds to a reaction scheme consisting of the main reaction and an undesired, competing subsequent reaction in which the product formed via the main reaction reacts with unreacted educt to form an undesired subsequent product. The subsequent product may be analyzed in an easy way via absorption spectra. The quality of the mixing process is thereby evaluated through the selectivity of the undesired subsequent product S, X_S. The more S is formed, the poorer is the mixing.

The investigations for performing rapid chemical reactions by means of microstructure mixing was done in the equipment represented in Fig. 6. It consists of the supply containers 5 for the starting components A and B, metering and control devices 6, filters 7 for protecting the microstructure mixer against plugging, the microstructure mixer 8 and the receiving container 9 for the product mixture. The microstructure lamellae mixer has slit channels with a depth d of 70 µm and a width b of 4 mm. The microstructure lamellae mixer was thereby compared with a microstructure mixer with rectangularly shaped microchannels which generate free jets[12] with a width of 100 µm and a thickness of 70 µm. A conventional flat jet nozzle was further included in the comparison. The jets in the two microstructure mixers were arranged such that the components A and B emerge from the mixer in layers arranged alternating on top of one another.

Volumetric flow conditions were adjusted of $\alpha = V_A/V_B$ of 10. One thereby operated at performance coefficients of $\psi > 10^2$. The reaction kinetics data and the specifications for the utilization of the model reactions may be gathered from the literature [2, 8, 9, 10].

A stoichiometric ratio of 1.05 and a constant starting naphthol concentration of 1.37 mol/m^3 were set. The performance coefficient ψ is calculated as follows:

$$\psi = (\Delta p_{Naph.} \cdot V_{Naph.} + \Delta p_{Salt} \cdot V_{Salt}) / [k_2 \cdot c_{at} \cdot \eta \cdot (V_{Naph.} + V_{Salt})]$$

with

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[12] literal translation

$\Delta p_{Naph.}$ loss of energy due to impact [for the] naphthol solution in the mixer

$\Delta p_{Sulf.}$ loss of energy due to impact [for the] sulfanilic acid solution in the mixer

$V_{Naph.}$ volumetric flow [of the] naphthol solution

$V_{Sulf.}$ volumetric flow [of the] sulfanilic acid solution

k_2 specific reaction rate of the undesired subsequent reaction

c_{a0} starting concentration of naphthol

η dynamic viscosity

In **Fig. 7**, the selectivity of the undesired subsequent product X_s is plotted against the performance coefficient ψ.

It emerges that considerably less undesired subsequent product is formed when using the microstructure lamellae mixer and the microstructure mixer for the volumetric flow ratio of $\alpha = 10$ at an equal performance coefficient, then when using a conventional flat jet nozzle. This finding is entirely surprising if one starts out from the existing teaching that the intensity of mixing is determined solely by the performance coefficient and the material data. The mixing behavior of the microstructure lamellae mixer is thereby approximately equal to that of the microstructure mixer, whereby essential advantages of the microstructure lamellae mixer consist in that the pressure loss through friction is smaller by at least a factor of 3 and, based on a lower number of fluid elements, a lesser back-mixing through the turbulence at the entrance into the mixing/reaction chamber.

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Mixing and Fast Chemical Reaction I: Test Reactions to Determine Segregation
Chem. Eng. Sci. 36, 1981, 1643

Patent Claims

1. Process for performing chemical reactions between reaction partners (educts) in the form of gas and/or fluids, in which at least two educts A, B are each subdivided by an associated system of micro-channels into spacially separated microstreams, which then emerge into a common mixing/reaction chamber, **characterized in** that the microstreams in the form of fluid lamellae of the educts A, B coming from slit-shaped micro-channels (micro-slit channels) are allowed to emerge into a mixing/reaction chamber (4) at flow rates equal for each of the educts, whereby each fluid lamella of an educt A is lead into the mixing and reaction chamber (4) in the direct vicinity to a fluid lamella of another educt B and the neighboring fluid lamellae mix with one another through diffusion and/or turbulence

2. Process according to claim 1, characterized in that laminar flow conditions are maintained in the microchannels (1a, 1b) for the educts A, B.

3. Process according to claim 1 through 2, characterized in that the fluid lamellae of the educt A, B emerge into the reaction chamber (4) in thin layers lying alternating on top of or next to one another.

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[1] *Microreactor for Performing Chemical Reactions with a Strong Heat Tonality*

4. Process according to claim 1 through 3, characterized in that the thickness of the fluid lamellae when entering the mixing/reaction chamber is adjusted to a value between 10 µm and 1000 µm, preferably between 10 and 100 µm.

5. Process according to claim 1 through 4, characterized in that a fluid lamella of a thermostated inert fluid is additionally fed into the mixing/reaction chamber (4) in the vicinity of a fluid lamella of an educt.

6. Microstructure lamellae mixer with at least one mixing chamber and one preceding structural guiding part for the supply to the mixing chamber of fluids to be mixed, whereby the structural guiding part is composed of a plurality of plate-like elements layered on top of one another, which are passed through by channels running diagonally with respect to the longitudinal axis of the micromixer, and whereby the channels of neighboring elements cross-over contact-free and emerge into the mixing chamber, characterized by the following characteristics:

a) The plate-like elements consist of thin foils (1, 2) into each of which are incorporated individual or a system of closely neighboring, slit-shaped microslit channels (1a, 1b) that run with alternating opposite inclinations to the longitudinal axis (3) of the micromixer, such that when layering the foils (1, 2) on top of one another, one channel each or a row each (1a and 1b) forms of closed channels for the guiding of the fluids to be mixed (educts A, B);

b) The microslit channels (1a, 1b) have a depth of $d < 1000$ µm, preferably < 100 µm, a width b which is at least 10 times the respective depth d [that was] selected (i.e., $b/d >= 10$) and a wall thicknesses of the channel bases (5a, 5b) of < 1000 µm, preferably < 100 µm;

c) the orifices of the channels (1a, 1b) bordering the mixing chamber (4) lie in alignment above one another, whereby the channels (1a, 1b) of neighboring foils diverge towards the fluid-entry side (3a, 3b) of the micromixer such that the mixing fluids (A, B) may be fed separately.

7. Microstructure lamellae mixer according to claim 6, characterized in that the channel bases (5a, 5b) are supported against one another at regular intervals through pins (15) rigidly connected to the channel bases (5a, 5b).

8. Microstructure lamellae mixer according to claim 6, characterized in that an intermediate foil (8) is intercalated between each two foils (1, 2) with the inclined

microslit channels diverging towards the fluid input side, which [intermediate foil] has microslit channels (9) running perpendicularly to the longitudinal axis (3) of the micromixer and serves in guiding through a cooling or heating agent.

9. Microstructure lamellae mixer according to claim 6 or 7, characterized in that a micro-heat-transfer [system] (10) is connected to the mixing chamber (4).

10. Microstructure lamellae mixer according to claim 6 or 7, characterized in that the mixing chamber is designed as micro-heat-transfer [system], which is connected directly to the structural guiding part 13.

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